Cable modelling with neutral

This document summarises the modelling of 4 wire cables (3 phases + neutral) in PowerFactory. The modelling of a cable type (TypLne) is based on a given data sheet as well as data and formulas from available literature.

1 Input parameters in PowerFactory

See Technical Reference [1] of TypLne.

1.1 TypLne with 3 Phases

In the general line type (TypLne) with 3 phases and no neutral, the return path in modelled via the zero-sequence impedance. Any return path (via neutral, via earth, via neutral and earth etc.) can be modelled by defining the corresponding zero sequence parameters. Only one return path can be modelled per line type.

Figure 1 shows the input parameters:

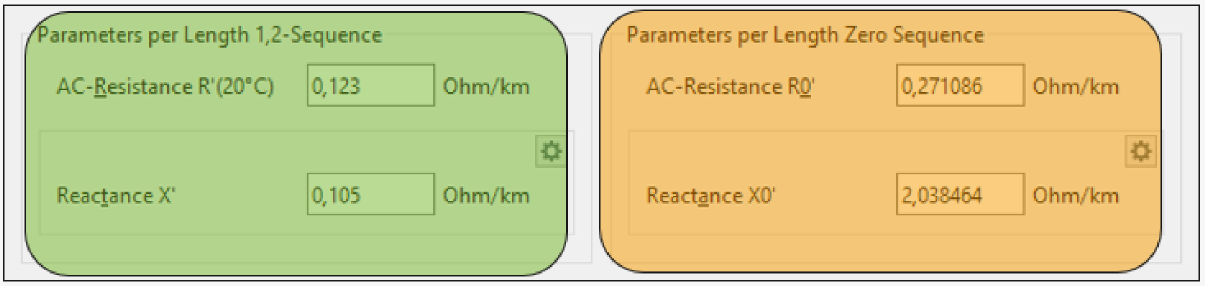

Figure 1: Input parameters of TypLne with 3 phases and no neutral

The modelling of a TypLne with 3 phases and no neutral is useful if only one return path in the network shall be investigated.

1.1.1 1,2 sequence

Data is usually given in data sheets

1.1.2 zero sequence

Contains any return path (including neutral).

- return path via neutral
- return path via earth
- return path via neutral and earth
- …

The input data is usually not given in data sheets but can be determined from measurements or with formulas from literature [2] [3].

Common assumption:

- Z0/Z1 = 4 (valid when return path is only via neutral and the cross section of neutral and phase conductors are the same)

1.2 TypLne with 3 Phases + Neutral

In the general line type (TypLne) with 3 phases and neutral conductor, different return paths can be modelled.

Figure 2 shows the input parameters:

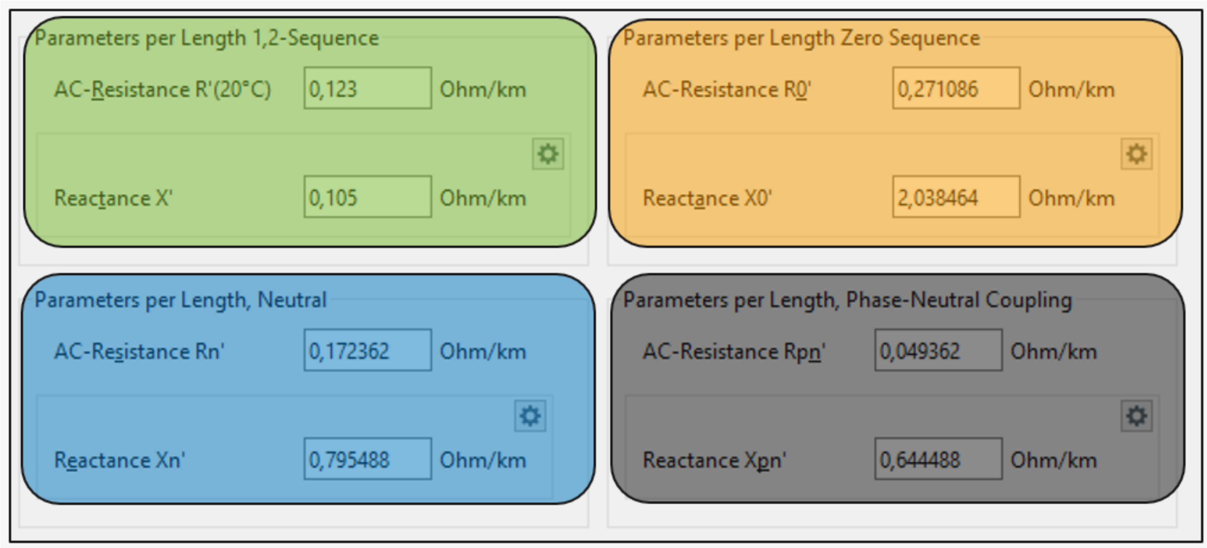

Figure 2: Input parameters of TypLne with 3 phases and neutral

1.2.1 1,2 sequence

Data is usually given in data sheets (same vales as in chapter 1.1)

Input in PowerFactory: R_1, X_1

1.2.2 zero sequence

The zero-sequence impedance Z_{0E} contains the return path via earth (or PE/sheath). The impedance can be determined via the phase-earth loop shown in Figure 3.

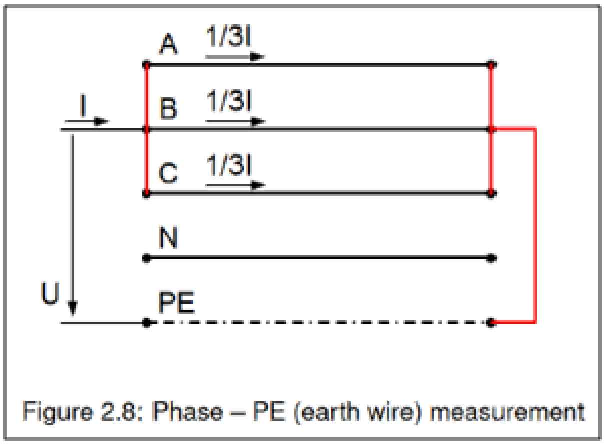

Figure 3: Phase-earth loop [1]

Equation of phase-earth loop:

$$Z_{0E} = Z_1 + 3 \cdot Z_{earth} \tag{1}$$

The impedance Z_{earth} can also contain the PE conductor and is explained in more detail in chapter 1.2.4.

To determine the zero-sequence impedance Z_{0E} with return path via earth one can use measurements or general formulas from literature [2] [3]. As a simplified estimation, given quotients of Z_{0E}/Z_1 from the literature [2] [3] (return path only via earth) can also be used.

Input in PowerFactory: R_{0E}, X_{0E}

1.2.3 Neutral

The input of the neutral in the TypLne contains the impedance of the neutral-earth loop ($Z_n = Z_{NE}$) as shown in Figure 4.

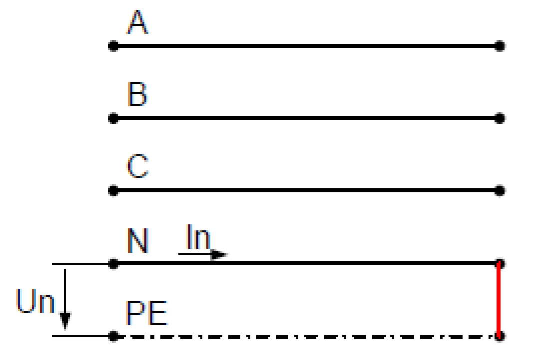

Figure 2.7: Neutral to ground measurement loop

Figure 4: Neutral-earth loop [1]

Equation of neutral-earth loop:

$$Z_{NE} = Z_{earth} + Z_{neutral} \tag{2}$$

The impedance Z_{earth} can also contain the PE conductor and is explained in more detail in chapter 1.2.4.

The impedance $Z_{neutral}$ contains the neutral conductor, which can be determined via the phase-neutral loop as shown in Figure 5.

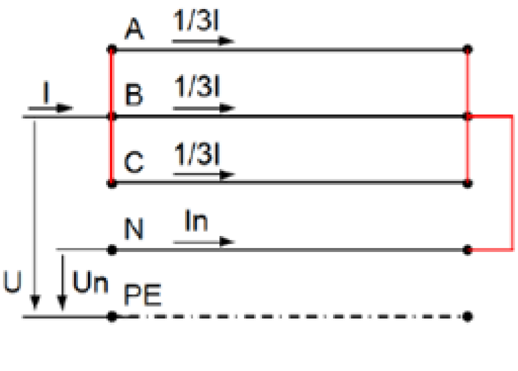

Figure 2.9: Phase – neutral measurement

Figure 5: Phase-neutral loop [1]

Equation of phase-neutral loop:

$$Z_{0N} = Z_1 + 3 \cdot Z_{neutral} \tag{3}$$

To determine the zero-sequence impedance Z_{0N} (return path only via neutral) one can use measurements or general formulas from literature [2] [3]. As a simplified estimation, given quotients of Z_{0N}/Z_1 from the literature [2] [3] (return path only via neutral) can also be used.

After determining Z_{0N} equation (3) can be used to calculate $Z_{neutral}$ and together with Z_{earth} one can determine the input parameter Z_{NE} with equation (2).

Input in PowerFactory: $\mathbf{R}_{NE}$, $\mathbf{X}_{\mathrm{NE}}$

1.2.4 Phase-neutral coupling

The input data of the phase-neutral coupling contains in PowerFactory the impedance Z_{earth} which is part of the phase-earth loop impedance Z_{0E} which can be calculated by using equation (1).

Input in PowerFactory: $\mathbf{R}_{earth}$, $\mathbf{X}_{\mathbf{earth}}$

2 Calculation of the input parameters in PowerFactory

As an example, the cable type **NYCWY 4x70/35** with available input data from data sheets is used to model a TypLne with 3 phases and neutral conductor. This cable type has three copper conductors (phases), a neutral conductor and a concentric copper conductor (shield or sheath). The return path can therefore be either via earth and sheath or via the neutral. In this case, the sheath will be represented by the neutral in the TypLne.

Available data from the data sheet are listed in the following table:

Table 1: Available data in data sheet of cable type NYCWY 4x70/35

Variable	Value	Unit
Conductor resistance R_L	0,268	Ohm/km
Inductance L	0,262	mH/km
Cross section conductor A_L	70	mm²
Cross section sheath/shield A_S	35	mm²
Outer diameter of cable D_A	36,8	mm
Nominal current in air $I_{r,air}$	199	A
Nominal current in earth $I_{r,earth}$	234	A

The following calculations can be seen in the Excel sheet “NYCWY”.

2.1 Step 1: positive sequence

With the input data from Table 1 the positive sequence data can be determined:

- $R_1 = R_L$
- $X_1 = 2 \cdot \pi \cdot f \cdot L$

where f is the frequency in Hz.

2.2 Step 2: phase-earth loop

The assumption for this cable is that one return path is via earth and sheath ($Z_{0E} = Z_{0SE}$). Therefore, the impedance Z_{0SE} for this case has to be determined. Literature, such as [2] [3] give general equations with which this impedance can be calculated.

From [3] equation (32):

$$Z_{0,SE} = R_L + 3\omega\frac{\mu_0}{8} + j\omega\frac{\mu_0}{2\pi}\left(\frac{1}{4} + 3ln\left(\frac{\delta}{\sqrt[3]{r_L \cdot d^2}}\right)\right) - 3\frac{\left(\omega\frac{\mu_0}{8} + j\omega\frac{\mu_0}{2\pi} \cdot ln\left(\frac{\delta}{r_{sm}}\right)\right)^2}{R_S + \omega\frac{\mu_0}{8} + j\omega\frac{\mu_0}{2\pi} \cdot ln\left(\frac{\delta}{r_{sm}}\right)}$$

where μ_0: magnetic constant $[Vs/Am]$

ω: angular frequency [1/s]

δ: earth current depth [m] (from [2])

r_L: conductor radius (from [3] Table 12) [mm]

d: mean distance of the conductors (from [3] Table 12) [mm]

r_{sm}: mean radius of the sheath/shield (from [3] Table 14) [mm]

R_S: resistance of the sheath/shield (from [3] Table 14) [Ohm/km]

Alternatively, $Z_{0,SE}$ can be determined via given impedance ratios Z_0/Z_1 when earth return path via earth and sheath/shield.

2.3 Step 3: Impedance Z_{earth}

The impedance Z_{earth} can be calculated with equation (1) from chapter 1.2.2 with ($Z_{0E} = Z_{0SE}$).

2.4 Step 4: Phase-neutral loop

The assumption is for this cable that the return path is via the neutral. The impedance Z_{0N} can be calculated with general formulas or by usage of given impedance rations Z_{0N}/Z_1 (which is done here).

According to [2], Table A.14.5 and A14.3 with "Rückleitung a" (= return path only via neutral) and "Kupfer" (= copper conductors), the impedance rations can be determined.

2.5 Step 5: Impedance $Z_{neutral}$

The impedance $Z_{neutral}$ can be calculated with equation (3) from chapter 1.2.3 .

2.6 Step 6: Neutral-earth loop

The impedance Z_{NE} of the neutral-earth loop can be calculated with equation (1) from chapter 1.2.3.

3 Calculation of the 1-phase fault

To verify the 4-phase cable type and compare it to the equivalent 3 phase cable types, short circuit calculations are executed. Below the equations for the calculation of a 1-phase fault can be seen:

General:
$$\underline{I}''_{\mathrm{k1}} = \frac{\sqrt{3}\cdot c\cdot \underline{U}_{\mathrm{n}}}{\underline{Z}_1+\underline{Z}_2+\underline{Z}_0} \tag{4}$$

Assumption: $\underline{Z}_1 = \underline{Z}_2$

1-Phase to Neutral:
$$\underline{I}''_{\mathrm{k1}} = \frac{\sqrt{3}\cdot c\cdot \underline{U}_{\mathrm{n}}}{2\cdot\underline{Z}_1+\left(\underline{Z}_1+3\cdot\underline{Z}_{\mathrm{neutral}}\right)} \tag{5}$$

Single Phase to ground:
$$\underline{I}''_{\mathrm{k1}} = \frac{\sqrt{3}\cdot c\cdot \underline{U}_{\mathrm{n}}}{2\cdot\underline{Z}_1+\left(\underline{Z}_1+3\cdot\underline{Z}_{\mathrm{earth}}\right)} \tag{6}$$

1-Phase, Neutral to Ground:
$$\underline{I}''_{\mathrm{k1}} = \frac{\sqrt{3}\cdot c\cdot \underline{U}_{\mathrm{n}}}{2\cdot\underline{Z}_1+\left(\underline{Z}_1+3\cdot\frac{\underline{Z}_{\mathrm{neutral}}\cdot\underline{Z}_{\mathrm{earth}}}{\underline{Z}_{\mathrm{neutral}}+\underline{Z}_{\mathrm{earth}}}\right)} \tag{7}$$

The Excel sheet "NYCWY" shows the corresponding hand calculations.

With the project "NYCWY 4x70_35.pfd" the results can be verified in PowerFactory.

4 References

[1] DIgSILENT, *Technical Reference - Overhead Line Models,* 2022.

[2] D.Oeding and B. Oswald, *Elektrische Kraftwerke und Netze.*

[3] IEC60909-2, *Short-circuit currents in three-phase a.c. systems – Part 2: Data of electrical equipment for short-circuit current calculations, Edition 2.0,* 2008-11.

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